INTERSIL D.C. Servo Motor Systems Using the ICH8510

INTRODUCTION

Intersil has developed a family of hybrid power operational amplifiers – the ICH8510 family – designed specifically for driving D.C. servo motors, D.C. linear and rotary actuators, electronic orifice valves and X-Y printer motors. There are three members of this family, the ICH8510, 8520 and 8530, capable of delivering 1 amp, 2 amps and 2.7 amps respectively, while operating at supply voltages up to ±35V.

The amplifiers operate in the linear mode and can be treated as high power (and higher voltage) versions of a μA 741 operational amplifier. The ICH8510 can typically swing ±26V across a 20Ω load and the 8520, 8530 versions can typically swing ±26V across a 10Ω load with supplies of ±30V. The typical quiescent current under no load conditions is ±20mA while input offset voltage, input bias current, slew rate, open loop voltage gain and input voltage range are the same as the basic 741 differential, operational amplifier. All the amplifiers are short circuit proof, being able to withstand indefinite shorts to ground at the output and also have unique safe area operating protection. This safe area protection allows the amplifier to handle the large inductive emf's caused by D.C. motors during reversal or load changes without damage, but does not hinder normal operation of the amplifier.

The open loop configuration of the ICH8510 family makes them very versatile for closed loop servo motor systems. Either positive or negative gains may be obtained using well known operational amplifier techniques. The ease with which the ICH8510 amplifier family can be implemented, relieves system designers of the headaches of excessive quiescent power supply currents, and inadequate amplifier stability. The power amplifiers are <u>internally</u> <u>compensated</u> and are available in an eight pin TO-3 package. They are unconditionally stable down to unity gain, non-inverting (the worst case).

SERVO SYSTEMS

BACKGROUND

Figure 1 shows the ICH8510 in an "open loop" control system, meaning that the motor is not within the closed loop of the amplifier and the associated feedback components. Figure 2 and 3 show the ICH8510 in typical open loop system applications.

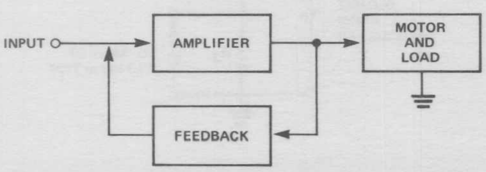

FIGURE 1: Open Loop Control System

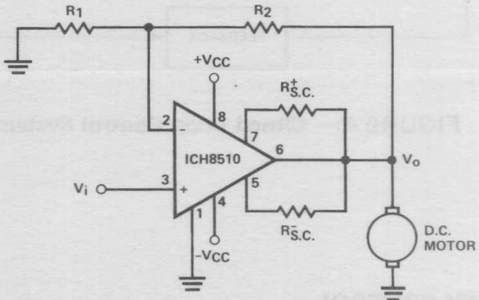

FIGURE 2: Non-Inverting Gain Configuration

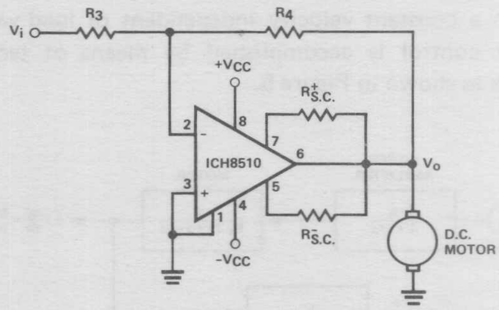

FIGURE 3: Inverting Gain Configuration

Figure 2 shows the ICH8510 in the standard non-inverting operational amplifier configuration where the voltage gain

$$A_V = \frac{V_o}{V_i} = \frac{R_2 + R_1}{R_1} = 1 + \frac{R_2}{R_1}.$$

In Figure 3 the power amplifier is shown in the standard inverting gain configuration where the voltage gain

$$A_V = \frac{V_o}{V_i} = -\frac{R_4}{R_3}.$$

The resistors denoted $R^{+}_{S.C.}$ and $R^{-}_{S.C.}$ determine the current which will flow under output short circuit conditions from the output to ground. Such short circuits could come about as a result of a stalled motor where the only load resistance is the winding of the motor.

In an open-loop system any changes in the input, load or amplifier characteristics will cause corresponding changes in the output. In order to minimize those output deviations a closed loop system is normally used. With a closed loop system a portion of the system output is fed back to the input and summed with the input. Now the motor is actually part of the feedback network and variations which would occur in the open-loop system are divided by the feedback ratio.

Servo systems control basically three quantities or any combination of the following three quantities:

1. Motor velocity
2. Motor position (i.e., shaft rotational position)
3. Motor torque

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A block diagram of a typical closed loop control system is shown in Figure 4.

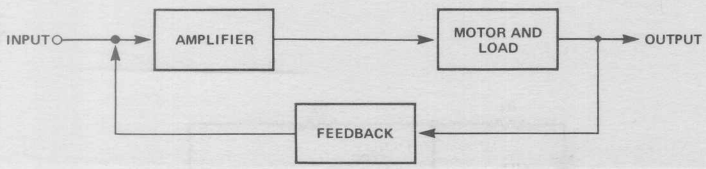

FIGURE 4: Closed Loop Control System

VELOCITY CONTROL

The purpose of a closed loop velocity control system is to maintain a constant velocity independent of load variations. Velocity control is accomplished by means of tachometer feedback as shown in Figure 5.

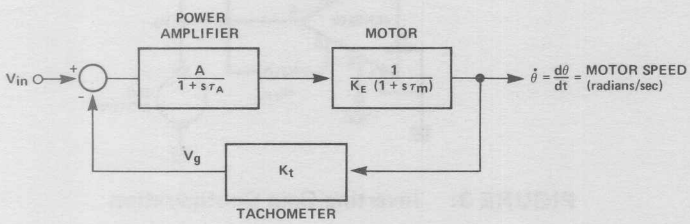

FIGURE 5: Velocity Control System

Where:

- A = D. C. gain of amplifier
- τ_A = dominant pole of amplifier
- K_E = voltage constant of motor
- τ_m = dominant pole of motor
- K_t = tachometer constant

The model of the velocity control system shown in Figure 5, while not being an exact representation of the real system, allows the transfer function of the closed loop system to be determined. The transfer function is given by:

$$\frac{\dot{\theta}}{V_{in}} = \frac{\left(\frac{d\theta}{dt}\right)}{V_{in}} = \frac{\left(\frac{1}{1+S\tau_A}\right)\left(\frac{1}{K_E(1+S\tau_m)}\right)}{1+K_t\left(\frac{A}{1+S\tau_A}\right)\left(\frac{1}{K_E(1+S\tau_m)}\right)} \qquad (1)$$

This form allows variations of the system parameters to be related back to the variable of most interest, which is the motor rotational speed or ω. A root locus of (1), may be drawn to determine overall stability with variations in the systems parameters.

The actual circuit implementation is presented in Figure 6 where the ICH8510 is used as both the driving amplifier and the summing amplifier.

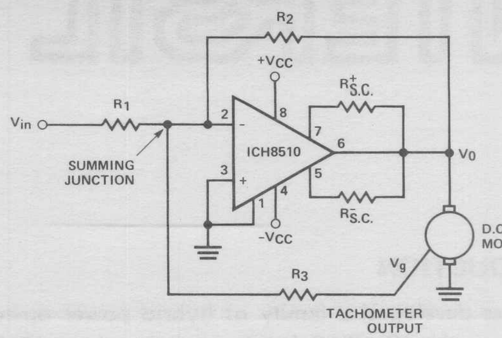

FIGURE 6: Velocity Control Realization

The output voltage of the amplifier is given by the following equation:

$$V_O = -\frac{R_2}{R_1} V_{in} + \left(-\frac{R_2}{R_3}\right) V_g. \qquad (2)$$

The operation of the velocity control system can be understood from the following: if the speed of the motor tends to increase for whatever reason (i.e., less load friction), a larger voltage is induced in the windings of the tachometer. This voltage is fed back to the summing junction and opposes the input voltage which forces the output voltage down tending to keep the speed constant.

For some applications it may be desirable to monitor the rev/sec or rev/min of the motor shaft. This can be done very easily by using Intersil's ICL7106 or 7107, which are single chip 3–½ digit A/D Converters, and a simple scaling network connected to the tachometer output. By knowing the volts/r.p.m. rating of the tachometer, a simple resistor divider network can be constructed to scale the tachometer output voltage so the input of the A/D Converter will indicate motor speed directly. Here is an example:

$$\frac{\text{Tachometer Output}}{\text{Tachometer Constant}} = \frac{12V}{3V/1000\text{ r.p.m.}} = 4000\text{ r.p.m.}$$

The output of the A/D should indicate 4.00 Kr.p.m. The output voltage of the tachometer is scaled down as in Figure 7. Since the optimum full scale input voltage of the 7106 or 7107 is 200mV the reading of 4.00 Kr.p.m. should be scaled to correspond to 40mV at the input of the converter. The decimal point may be shifted so that the display, which the converter drives, will read 4.00.

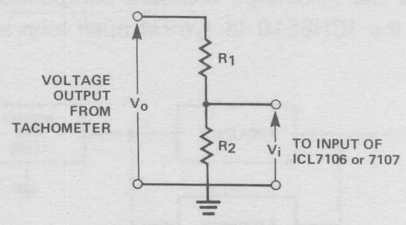

FIGURE 7: Divider Network for A/D Converter Input

Now,

$$V_o = 12V \text{ and } V_i = 40mV$$

so R_1 and R_2 are determined by

$$V_i = \frac{R_2}{R_1 + R_2} V_o.$$

This equation cannot be solved by itself but by using the minimum load resistance of the tachometer as the second equation yields $R_1 + R_2 = Z_{Lmin}$. Using 10KΩ for $R_1 + R_2$, the value of R_2 is 34Ω and R_1 = 9.96KΩ.

POSITION CONTROL

The purpose of a closed loop position control system is fast and accurate control of the rotational position of the motor shaft. The position control may be random position changes or may occur at equal intervals of time with the position changes also being of equal distance. Rotational position is given the notation of θ, which signifies the angle deviation from a set reference angle. θ is equal to the integral of the angular velocity. The block diagram of a position control system is shown in Figure 8.

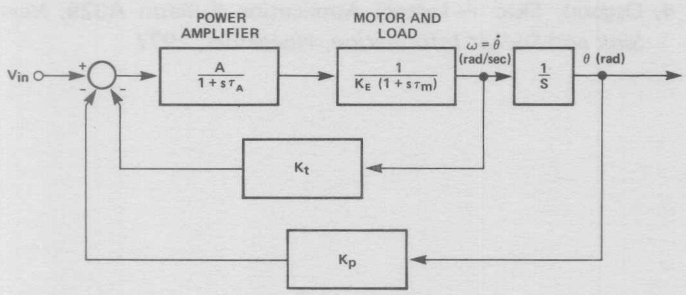

FIGURE 8: Position Control System

The only parameters in Figure 8 that differ from the velocity control system in Figure 5 are:

K_p = integrator constant
$1/S$ = the integrator transfer function

From Figure 8 the transfer function of the position control system may be written and is equal to:

$$\frac{\theta}{V_{in}} = \frac{\frac{1}{S}\left(\frac{A}{1+S\tau_A}\right)\left[\frac{1}{K_E(1+S\tau_m)}\right]}{1+\frac{K_tK_p}{S}\left(\frac{A}{1+S\tau_A}\right)\left[\frac{1}{K_E(1+S\tau_m)}\right]} \qquad (3)$$

Here again the form of the transfer function given by (3) allows the effects of variations in system parameters to be determined.

While the block diagram at first glance seems a bit formidable, the functions of the integrator and integrator constant are both performed by a simple potentiometer coupled to the motor shaft. The equivalent circuit of the coupled pot is shown in Figure 9.

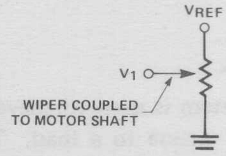

FIGURE 9: Position Control Potentiometer

As the motor shaft turns, the wiper voltage varies from zero volts at the 0° reference point to V_{REF}. This output voltage then varies as $\frac{d\theta}{dt}$, which is the rotational speed of the motor; and this voltage is $\frac{dV_1}{d\theta}$. Referring to Figure 10 helps clarify this point.

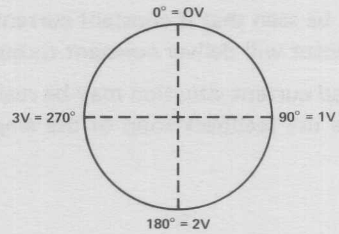

FIGURE 10: Relationship Between Angular Position and Pot Wiper Voltage

For the conditions in Figure 10 a reference voltage, V_{REF} = 4V and a scaling factor of 1V/90° exists.

A complete position control system is shown in Figure 11.

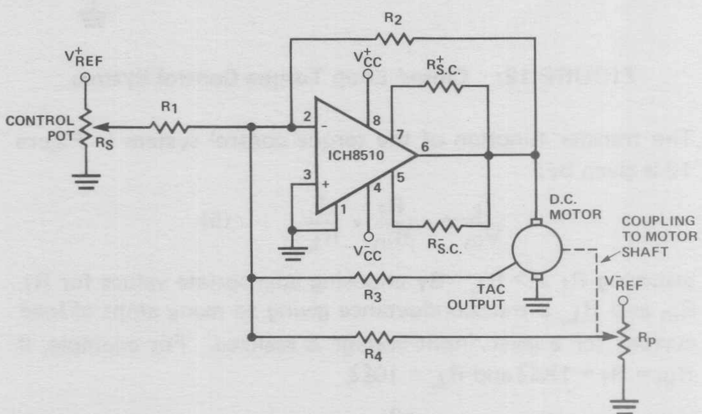

FIGURE 11: Practical Position Control System

The circuit of Figure 11 operates as follows: When the control pot is turned to a new position the motor begins turning until the voltage at the wiper of the motor pot produces a voltage which causes the output voltage to reach zero and the motor stops. At this point, the two voltages produced by the gains from the control pot and from the motor pot produce equal and opposite voltages at the output of the ICH8510 and this causes the motor to stop. If the load on the motor tries to turn the shaft to another position a voltage is produced which opposes the change in position and forces it to remain in the preset position. The control pot should be a 10 turn pot in order to obtain very accurate position control and may be calibrated to indicate angular position or linear position of the load.

TORQUE CONTROL

A torque control system is used whenever a motor is required to provide constant torque to a load. The torque of a D.C. motor is directly proportional to the motor current, the only difference being the torque constant of the motor. The relationship between the torque and motor current is given by the following relationship:

$$T = K_T I \quad (4)$$

Where:

K_T = torque constant
T = motor torque
I = motor current

From (4) it can be seen that if constant current is delivered to the motor the motor will deliver constant torque.

The constant load current situation may be realized by placing the motor inside the feedback loop of the amplifier as shown in Figure 12.

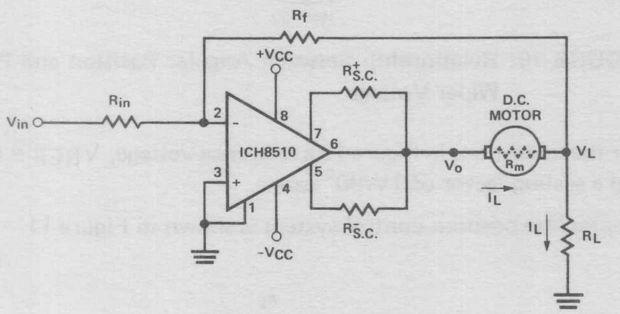

FIGURE 12: Closed Loop Torque Control System

The transfer function of the torque control system in Figure 12 is given by:

$$\frac{I_L}{V_{in}} = -\frac{R_f}{R_{in}} \cdot \frac{1}{R_L} \quad (5)$$

assuming $R_f \gg R_L$. By choosing appropriate values for R_f, R_{in} and R_L, a transconductance giving so many amps of load current for a given input voltage is realized. For example, if $R_{in} = R_f = 1K\Omega$ and $R_L = 10\Omega$,

$$\frac{I_L}{V_{in}} = -\frac{1 \times 10^3}{1 \times 10^3} \cdot \frac{1}{10} = -10^{-1} \text{A/Volt}.$$

The operation of the torque control system can be understood from basic operational amplifier theory. For a constant input voltage designated V_{in}, the current through R_{in} is $\frac{V_{in}}{R_{in}} = I_{in}$ and the current through the feedback resistor R_f is given by $\frac{V_L}{R_f} = I_f$; both of these under the assumption that the inverting input is a virtual ground. These two currents will be equal to one another assuming the input bias current is negligible, which results in a constant output voltage. With a constant load R_L the current through the load resistor and also the motor will be constant. This means under stall conditions, the amplifier delivers the same current as when in the unstalled mode. In effect, the stalled current of, say, Figures 2 or 3 will approach maximum output current of the amplifier. This difference is quite significant, i.e., a 1 amp at 24V motor during ing normal unstalled conditions becomes a 2-3 amp motor (this maximum limit is set by externally programmable R_{SC}^+ and R_{SC}^- resistors) for stalled conditions. The Figure 12 circuit would keep the 1 amp drive current constant whether the motor was stalled or not.

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